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averting grid collapse

system control & restoration in emergency conditions

THE AUGUST 14 BLACKOUT HAS made review of our electrical power system an urgent national priority. Effective organizational structure, well-developed yet flexible procedural rules, and a high level of competence in the electric system control room are essential to grid reliability. Indeed, as illustrated in the case study presented here, these elements can limit the severity of real and potential emergencies and avert cascading outages even when the system is constrained by a less-than-optimal physical infrastructure.

This article focuses on how the Midwest Independent Transmission System Operator and American Transmission Company managed a disaster recovery event of significant proportions and duration following outages caused by a flood in the Upper Peninsula of Michigan in May 2003. It is an example of how transmission system operators avoid system collapse and isolation and prevent cascading outages over a wider portion of the electric transmission delivery system in a region.

Grid Operations Under Deregulation

The electric system—the grid—is a composite of multiple systems, with ownership of generation, transmission, and distribution held by multiple corporate entities in various combinations. A few companies, such as American Transmission Company, own and operate transmission only. Deregulation requires equal access to transmission regardless of ownership.

Operational control of the grid is the responsibility of transmission system control operators, working in the control center of the transmission provider. They manage the transmission path for generation dispatchers and distribution system operators, balancing supply and demand. Local emergencies, such as those caused by storms, usually involve only distribution companies, responsible for delivering power from the grid to individual customers. In contrast, system restoration under blackout (or potential blackout) conditions involves all three components of the grid: generation, transmission, and distribution.

Deregulation creates separate and distinct relationships among generation, transmission, and distribution. It also requires that information be shared equally among these entities. The Standards of Conduct established by FERC Order 889 insist that information be shared in real time via OASIS. However, in emergency circumstances affecting system reliability, transmission providers may take whatever steps they deem necessary to keep the system in operation.

During an emergency, especially when a blackout is imminent, it is essential for all parties to communicate frequently and openly. System operators must have the ability to openly communicate with generation (including power plant operators) and distribution (for example, field personnel at substations). Posting communications on OASIS in real time is impractical under these circumstances. Communication must be direct and immediate. Thus, the Standards of Conduct must be suspended. If they are not suspended early in an emergency event, actions cannot be coordinated to minimize the impact to the system while averting further system degradation that may lead to a blackout.

Faced with an event of sizable proportions, with the potential for voltage collapse and cascading outages, the system operator is responsible for taking action to contain the situation and restore normal service. Sudden voltage collapse results in system separations and generators tripping at locations that are nearly impossible to predict. A major decision that system operators must consider in emergencies is isolation of an unstable area from neighboring electrical systems. Guidelines for making these decisions and parameters for system assessment are predetermined, so that operators know the latitude they have for preventive action, which can have economic consequences. Decisions under emergency conditions must be made with reliability as the sole criteria.

Transmission System Operations

The system operator monitors and assesses the capability of the grid in real time, the objective being to avoid any system single contingency event that would put the interconnection at risk. The system operator has a number of alternative courses of action to remediate the situation and keep the system secure. All of these actions are defined within the NERC Transmission Loading Relief Procedure (TLR).

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When the operating security limit (OSL) is at risk of violation, system operators take action according to a predefined set of rules—the TLR Procedure. The TLR is a procedure that allows the security coordinators to respect contractual obligations for transmission service and mitigate potential or actual operating security limit violations (OSLVs). TLR Procedures are restricted to the mitigation of actual or potential OSLVs.

Under the TLR procedure, a calculation is made for the portion of the constrained facility's loading due to firm point-to-point transmission service that must be curtailed in the interest of network security. The transmission provider performs this calculation to ensure that the curtailment is comparable and nondiscriminatory with respect to network integrated transmission service for native load.

The transmission operator and/or its reliability authority using supervisory control and data acquisition, energy management systems, and contingency analysis tools monitors the system continuously to ensure that it is operating with adequate margins for OSLs under pre- and postcontingency scenarios.

Voltage collapse and phase-angle instability can occur before reaction times of many automatic programs or manual action can be taken by transmission operators. These conditions must be mitigated on a precontingency basis. Most thermal overloads, on the other hand, can be withstood for a period of time that ranges from minutes to hours.

While taking actions to mitigate the potential for identified system security problems, operators must be careful to not unknowingly create conditions in which one line outage would trigger subsequent cascading outages. Studies must be conducted so that operators know the parameters within which action can be taken. The impact of changes in loads from one line to another must be analyzed in real time, and options must be developed in the context of the OSL at the moment. Contingency analysis must be performed under crisis conditions.

The TLR Procedure is a very useful tool that operators use to mitigate OSLVs. However, due to various contractual agreements and operating procedures, operators are very deliberate and circumspect about removing certain facilities from service when faced with a potential OSLV.

In a deregulated environment, the importance of TLRs is underscored by the FERC statement that "TLR is perhaps the most important transmission issue in the Midwest."

figure 1. Hoist dam. (Courtesy of City of Marquette.)

Dead River Flood

Description of Flood—Impending Threat

On 14 May 2003, an earthen flood control dam at the head of the Dead River breached, causing Silver Lake to empty into the Dead River System. The river immediately downstream reached flood stage. Early the next morning ATC was notified that the earthen dike at Silver Lake near the river's headwaters had been breached. The breach at Silver Lake, the first of six dams between the headwater and the river's mouth at Marquette's upper harbor, posed a serious potential threat to the Presque Isle plant. We Energies' (WEC) Presque Isle Power Plant is located near the point where the Dead River drains runoff water from 164 square miles of Marquette County into the Lake.

Uncontrolled shutdown of the Presque Isle plant would risk voltage collapse of the Upper Peninsula transmission system and, with transmission lines at their limits, possibly lead to cascading outages further south, past the Flow South Flowgate at Stiles. It was imperative that MISO and ATC be prepared. The sequence of events are reported in the MISO investigation report as follows:

> As a result of the threatened loss of the Presque Isle Generating Facility, at 0906, CDT, the MISO declared an emergency and posted its notice suspending the NERC Standards of Conduct on the Midwest ISO OASIS. Also, the MISO Reliability Coordinator posted the declaration of emergency along with the suspension of Standards of Conduct as a System Emergency on the Reliability Coordination Information System (RCIS).
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> Following the declaration of Emergency, ATC, together with the MISO, contacted affected transmission customers and generators that could provide assistance for a controlled shut down of Presque Isle Generating Facility and preventing voltage collapse of the Upper Peninsula transmission system. A conference call was held at 1000 CDT, including representatives from UPPCO, We Energies, Wisconsin Public Service Corporation, Edison Sault Electric Company, the City of Marquette Board of Light and Power, Consumers Power Company, Michigan Electric Cooperative System, the Michigan Public Service Commission, the Wisconsin Public Service Commission, ATC and MISO. Various options to maintain voltage support and to avoid voltage collapse as a result of the loss of Presque Isle Generating Facility were discussed, including starting of additional diesel-fired generations owned by UPPCO at various locations, together with reductions in load through interruptible load reductions and re-dispatch. Also, at this time, the next contingency was determined for the Upper Peninsula transmission system. At the conclusion of the call a plan was developed.

The action plan comprised three basic steps to be taken in the event the worst identified contingency would occur. That contingency would be the potential failure of the Hoist dam (see Figure 1).

- ✔ First, a TLR 4 would immediately be issued on the Flow South Flowgate at Stiles and instruction given to bring on generation at Escanaba, Gladstone, and Portage in the Upper Peninsula.
- ✔ Second, if the Hoist Dam failed, UPPCO would notify the ATC system operator and increase all available generation to the maximum (approximately 73 MW). Or, if the Presque Isle plant flooded prior to failure of the Hoist Dam, WEC would notify the ATC system operator and start the process for shutting down the plant.
- ✔ Third, ATC system operators would coordinate and control the shutdown of the Presque Isle plant. Upon notification by ATC, MISO would issue a TLR 5 curtailing 250 MW of NNL on a pro rata basis, according to the existing ATC/MISO TLR 5 Agreement. The ATC system operator would then notify WEC, WPS, and UPPCO system operators to shut down the Presque Isle plant and curtail load to maintain system stability.

Thus, all parties were communicating with one another and in agreement as to the actions to be taken. The lines of authority and working relationships were clearly established.

Operator Response

From a system operator point of view, the immediate concern was the impact a partial or total loss of the Presque Isle Power Plant would have on the OSL. Since an OSL violation could lead to voltage collapse, there would be no time to respond if the worst contingency occurred.

The Presque Isle Power Plant is a must-run facility, integral to reliable system operations in the Upper Peninsula; this local generation supplies reactive as well as real power. The system cannot serve all of the load without a number of the generating units at the Presque Isle plant in service. The loss of the Presque Isle Power Plant would have a serious impact on the OSL for the Flow South Flowgate. This flowgate between the Upper Peninsula and

Wisconsin is one of the most congested in the United States (see Figure 2).

Staff at the ATC Control Center was immediately mobilized, notifying ATC's upper management and the MISO. At the outset of the event, MISO's reliability coordinator and ATC staff were working in tandem to assess the situation. Together they agreed on the course of action in the event that the contingency (shutdown of the Presque Isle plant) occurred. The operations staff at MISO and ATC agreed that the OSL needed further study to minimize consequences to customers. Optimization of the real-time capability of the system would allow as much load as possible to be served. This would require studies on the system under operating conditions at the time.

The ATC operations engineering staff was called and assigned to perform studies. Using detailed voltage stability simulation programs, the engineering staff was able to conduct studies on the transmission system that would update the existing ATC transmission system models and optimize the ability to serve as much load as physically possible based upon current and anticipated conditions. The study results identified the capability of the actual system to operate under the OSL. (Operating guidelines for normal operations do not include studies on future events as unlikely as a dam breach. Commonly they are designed to prevent cascading overloads in a single contingency.) When study results were corroborated internally and with MISO, the new OSL was incorporated into a plan that was communicated to affected parties.

With the future OSL known, the impact on transmission service to customers in the affected area could be determined. The standing operating guide could be updated to reflect this new limit. With this information in the operating guideline, the system operators could take the action necessary to respond to an event. As system topology changes were anticipated—units coming on line, lines forced out of service, etc.—a review of the OSL was done to ensure that the transmission system was not operated above the OSL at any time. The operating guide was updated as needed as a result of these ongoing studies. Thus, at any given point, system operators knew what actions could be taken without causing the transmission system to fail. Due to this preparation, system operators were ready when the Tourist Park Dam failed, and subsequently over the next eight minutes all of the generators at Presque Isle plant were either removed from service or tripped. The

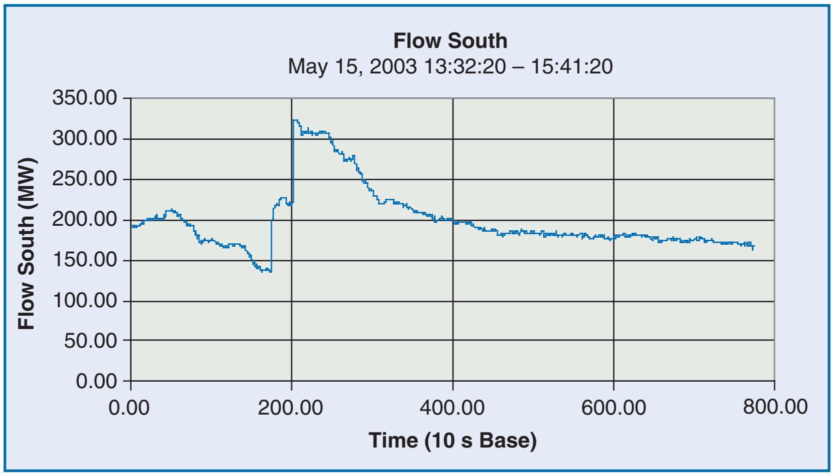

figure 2. Flow South chart. (Courtesy of American Transmission Company.)

flowgates were being watched closely enough to take action within minutes. The MISO had already been alerted and had suspended the standards of conduct, giving system operators the tools to manage the situation.

During the flood, the Tourist Hydro Dam was breached, causing the loss of a telephone cable on the trestle across the river and loss of local communications to the energy management system. ATC lost communication to a number of RTUs and consequently visibility of transmission status and flows near Presque Isle. This did not have impact on system operations, as it happened four minutes after ATC operators had requested relief on the flow south flowgate and notified UPPCO to drop load.

Flood Impact

The Presque Isle plant (see Figure 3) was shut down when flood waters from the Dead River rose to depths of four to five feet inside the plant, inundating and severely damaging the electrical and mechanical equipment. Further damage resulted from a breach in the bin wall that separates the plant's Lake Superior intake water from the Dead River.

The economic impact was significant. The affected mines were shut down indefinitely, since the two mines are dependent on electricity from the Presque Isle Power Plant. Nearly 1,100 workers were temporarily unemployed due to the mine closings, and the company lost the production of 250,000 tons of iron ore for each week the mines remained closed.

Flooding in the Upper Peninsula had created an emergency situation in which the Presque Isle Power Plant was no longer available for generation, and loads were being served from a combination of alternative sources, including bringing the mothballed Warden Power Plant (40 MW) into service. This was done in less than two weeks. UPPCO leased 24 diesel generators in trailers from Cummins Power (1.0 to 1.5 MW each), with capacity of about 20 MW.

Electric service was cut to all interruptible and curtailable customers that were on voluntary interruption programs. A public appeal was issued to reduce power consumption. UPPCO's customer base reduced power consumption to an average 60 MW/h during the evening and about 90 MW/h per hour during the day.

table 1. Electrical system in the upper peninsula of Michigan: Ownership and operational control.

Generation—We Energies (WEC)

The Presque Isle Power Plant is the largest generation facility in the Upper Peninsula. The Presque Isle Power Plant is owned by We Energies, Milwaukee, with load throughout the eastern half of Wisconsin and in the Upper Peninsula of Michigan. Generation dispatch of the Presque Isle Power Plant is performed from the We Energies System Operations Center in Waukesha, Wisconsin.

Generation & Distribution—City of Marquette

The City of Marquette has its own local generation and distribution. It is connected to the Presque Isle Power Plant via a 69 kV line.

Distribution—Upper Peninsula Power Company (UPPCO)

UPPCO is the major distribution utility in the western portion of Michigan's Upper Peninsula. UPPCO is owned by Wisconsin Public Service, Green Bay, Wisconsin. System control is performed by operators working from the WPS System Operations Center in Green Bay.

Transmission—American Transmission Company (ATC)

ATC is a stand-alone transmission company, which began operations on 1 January 2001, that owns and operates the former transmission assets of five investor-owned utilities and a variety of municipal and cooperatives in Wisconsin, a small portion of northern Illinois, and Michigan's Upper Peninsula. System operations are managed from two control centers in Wisconsin. It is a member of the Midwest ISO and is subject to MISO functional control with respect to operations.

ATC is both a transmission owner and operator. System control is performed by operators working from the ATC Control Center in Pewaukee, Wisconsin.

Regional Transmission Organization—
Midwest Independent System Operator (MISO)

The entire Upper Peninsula is within the Wisconsin/Upper Michigan subregion of the MISO. The MISO operations center is located in Carmel, Indiana.

Contingency Planning: Blackstart System Restoration

While the control of power flows in the Upper Peninsula continued, the possibility of voltage collapse and isolation due to unforeseen circumstances was considered to be present at all times. For this reason it was prudent to have an event-specific system restoration contingency plan in place. Existing plans were based on relationships established between vertically integrated utilities, before deregulation and the creation of a stand-alone transmission company with its own, separate operations control.

Communications and switching plans had to be developed that matched not only the situation and contingencies at the moment but also the relationships between generation, transmission, and distribution that matched the event and that would be in place in case of separation from the grid or system collapse.

The remedial measures taken in response to the flood affected power flows in the Upper Peninsula in ways that could lead to unforeseen events. The system restoration plan and studies anticipated voltage collapse in the Upper Peninsula, with the city of Marquette with its own generation and distribution, separating as an island. Its blackstart units were available to restore power in the UP Island. If the city of Marquette did not separate as an island, the plan would be initiated utilizing the temporary diesels newly installed at the Warden Plant and the combustion turbine at the city of Marquette. In any case, boundaries needed to be established.

The blackstart system restoration plan included the identification of blackstart units, in this case a CT owned by the city of Marquette. Agreement was reached on procedures for unit startup, cranking paths, switching, and communications. Instructions were written for buses to be cleared and later loads to be built. Priority loads were identified in advance and matched with circuits at substations.

Conclusions

The electric delivery system infrastructure, more commonly called the grid, as it currently exists, works most of the time. Regardless of the grid's physical limitations, its operation depends on the human and organizational resources that, when carefully structured and effectively managed, have succeeded in maintaining a high level of reliability despite the need for more physical modernization. Chief among these crucial nonphysical resources is the work done in control centers across the nation by operations engineers, reliability managers, outage coordinators, and system operators.

The event in the Upper Peninsula in May 2003 could have caused a black-

table 2. Timeline: Dead River flood.

0340	ATC operator on duty notified that Silver Lake earthen dike has been breached. Evaluation of impact on local generation—possible loss of Presque Isle plant
0445	Operator sends “significant event” message to system controllers
0512	MISO issues TLR 1 on FG 3544
0700	Operations supervisor and manager arrive at control room. Assessment.
0900	Operations manager meets with upper management.
0906	Upper management calls MISO—asks that FERC Emergency be issued.
0955	ATC and MISO notify FERC that Standards of Conduct are suspended.
1000	Conference call with ATC, MISO, WEC, WPS, UPPCO. Agreement on common Action Plan.
1019	Declaration of emergency posted on ATC and OASIS web site.
1148	MISO Reliability Coordinator issues TLR 4 on FG 3544. Redispatch UPPCO and ESE peakers/diesels—45 MW.
1347	Tourist Dam breached WEC notifies ATC that Presque Isle units 5 & 6 are coming off line. WEC curtails mine load 150 MW.
1400	Second conference call to discuss 1000 Action Plan.
1401	Presque Isle Generating Units 5 & 6 trip, followed by Unit 4.
1405	Presque Isle Generating Unit 7 trips. Controlled shut down of plant complete.
1406	ATC requests TLR 5 for relief on flowgate 3544 (250 MW)
1407	City of Marquette separates from Presque Isle bus.
1412	MISO issues TLR 5B on FG 3544.
1429	MISO asks ATC to bring FG 3544 below 220 MW due to thermal/stability limits
1530	Conference call with ATC, MISO, WEC, WPS, UPPCO regarding system status, temporary generation, redispatch of CTs.

figure 3. Presque Isle power plant. (Courtesy of City of Marquette.)

out in large portions of northern Wisconsin and Michigan’s Upper Peninsula. This was averted by the work of ATC system operators, working closely with the MISO, the regional reliability organization and the exceptional cooperation of local utilities, and in many cases their customers, including We Energies, Upper Peninsula Power Company, Wisconsin Public Service Corporation, Edison Sault Electric, Cloverland Electric Cooperative, the Michigan municipal utilities in Marquette and Escanaba, and the strong support of state regulators and emergency management officials. System collapse was avoided and loads were eventually restored to normal levels by all the components of the electric system working together. Thus, despite the condition of the physical system and supporting infrastructure, the organizational relationships, rules, procedures, and protocols are critical components of a functioning system.

Numerous operational lessons can be drawn from the response to the Dead River Flood by those responsible for the reliable operation of the electric system. As with any emergency event the first step is assessment. Subsequent steps depend on preparation, resources, and skill.

The lessons that can be drawn from this case study are summarized below.

Assessment. It is always useful to assume the worst at the outset, and prepare accordingly.

Communications. Communication among all players must begin immediately. Frequent—even continuous—communication between all parties is essential.

Standards of Conduct. The standards of conduct must be suspended as soon as possible, and suspension maintained for as long as necessary to allow open communications between transmission operators who are managing the restoration effort and generation and distribution with power and load that must be controlled.

Resources. All available resources must be called upon to assist with emergency response. In this case the involvement of the engineering staff to conduct studies of contingencies in real time is critical.

Action Plan. A formal action plan should be prepared as early as possible and updated as the system topology evolves.

Action and Implementation. System operators' decisions should be implemented as needed for contingency response, not delayed for market-based reasons. The maxim should be "act now, dispute later."

Contingency Planning (Blackstart). Detailed blackstart plans should be prepared in advance and updated periodically for use whenever remedial actions fail during high-risk periods.

Transmission Corridor Approach. All participants in each control area that is traversed by transmission lines should work together.

Control Authority. A single point of control should be established. Optimally, this should be a transmission operator with independent authority to act to protect the system. Reliability must be the overriding criteria for system operation.

Training. Working relationships should be established between transmission operators and neighboring generation and distribution utilities. Procedures and training across control area boundaries prior to events will contribute to communications during an event.

In a deregulated environment the decision to suspend the standards of conduct may be an essential first step in preventing system collapse. The difficulty is in determining at what point in time and under what circumstances this suspension should take place, before an event has occurred to allow preventive action to be taken. Once the standards of conduct are suspended, system operators can manage the system with the deregulated market as a secondary consideration, with contractual arrangements respected according to the TLR procedures through the highest level (TLR 6—Emergency Action).

Whether from natural disaster, weather, insufficient capacity, or insufficient transmission capability, the grid is at risk of failure in multiple locations at unknown times. Strengthening the infrastructure can lessen these risks but cannot fully eliminate them. Risks that do occur will be managed by system operators working within the organizational framework dictated by state and federal regulators. Stand-alone transmission operators bring a transmission corridor perspective to managing events and to planning for system restoration. This perspective as well as the relationships with generators and distribution utilities along transmission corridors and with neighboring utilities are essential contributors to the security of the grid regulatory obligation to honor all requests and to preserve all existing transactions that do not threaten the reliability of the system. Deregulation places economics in the decision-making process as operators develop their response to events that may potentially destabilize the grid. NERC Policy 9 clearly recognizes this when it calls on reliability coordinators to respect transmission reservation priorities and mitigate OSL violations at the same time. In striking the balance, timing may be the difference between failure and success. Lessons learned from a well-timed response, like the one described in this article, can contribute substantially to successful management of similar events in the future.

Acknowledgments

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